PROCEEDINGS

OF

THE ROYAL SOCIETY.

June 16, 1870.

XIV. "On the Atmospheric Lines of the Solar Spectrum, in a Letter to the President." By Lieut. J. H. HENNESSEY. Communicated by the President. Received May 21, 1870.

Mussoorie, April 25, 1870.

MY DEAR SIR,—I have the pleasure to enclose a map of the solar spectrum, including the region from the extreme red to the lines D, and a report on my endeavours to view the zodiacal light. A complete set of actinometric observations (simultaneous) between Dehra and Mussoorie has also been made. The latter observations are in course of reduction, and will, I trust, be submitted to you ere long.

2. *Instruments.*—The set of instruments which the President and Council of the Royal Society were good enough to send out to India under Lieut. Herschel's care, for my use, was duly handed to me at Bangalore (Madras Presidency) when I was on duty there in the winter of 1867–68. This set comprises a spectroscope with three flint-glass prisms, a hand-spectroscope, a tube with a double-image prism, and two of Hodgkinson's actinometers, as detailed in Professor Stokes's letter (list) addressed to the Under Secretary of State for India, dated 31 October, 1867.

3. *Narrative.*—On the completion of my duties at Bangalore I was enabled to bring the instruments up to Mussoorie, where the spectroscope was set up in May 1868. Meanwhile, however, the hot season in the plains had set in. The dust, as usual at this time of the year, filled the atmosphere, so that all hopes of obtaining spectroscopic observations of the sun about the time of sunset were in vain; and my endeavours to carry out the suggestions of the Committee, which they were so good as to make in connexion with my letter of 13 Feb. 1866, were reluctantly deferred to the ensuing October, when a clear atmosphere might again be expected.

4. *Position of observatory.*—With the permission of Colonel Walker, R.E., Superintendent of the Great Trigonometrical Survey of India, the spectroscope was placed in the small rotating dome observatory of the Survey department. It stands on the southernmost range of the Himalaya Mountains, in lat. N. 30° 27′ 41″, long. E. 78° 6′ 45″, height above mean sea-level 6937 feet. My observations were made in this observatory, excepting the interval last winter, when, in order to command a view of the sun down to the horizon, I shifted the instrument to an adjoining ridge.

5. *Times of observation.*—I was not long in ascertaining that between 10 A.M. and 2 P.M. no sensible alteration in the spectrum occurred. I am here speaking of the red end, which has almost exclusively been the subject of my study. Accordingly, the observations which may be called "sun high" were made between these hours. It was, however, some time before I discovered that by far the greater effect of the earth's atmosphere on the spectrum did not occur until the sun was about to dip* under the horizon. In fact it is only when the sun is some three or four diameters from the horizon that the very considerable alteration of the spectrum begins. To secure this condition, the atmosphere must be quite free from dust, which, as already implied, rises in great clouds from the plains until deposited by the heavy rains in July and August; and the sky must be clear of clouds, at least about the horizon. The lines were watched under these circumstances, and mapped down to the last moment before any serious diminution of light occurred. These results are given in the map observed "at sunset." It is easy to see that such favourable conditions cannot be expected continuously day after day; and even when available, the time for observation is so very limited, that no results can be obtained without considerable perseverance. When, however, this exceptional condition of air and sky do occur, the observer who has watched and become familiar with the spectrum sun high, is well rewarded by the decided manner in which the atmospheric lines now stand out, as the sun, still quite bright, is on the point of setting.

6. *Narrative resumed.*—Between May and October 1868 I employed my leisure in watching the spectrum sun high, fully expecting that the brilliant weather of the autumn would enable me to make every endeavour towards carrying out the suggestions of the Committee with the sun low. But the autumn came and the air was still hazy. In fact, while the average fall of rain here is some 90 inches, there fell in the season of 1868 only 61 inches, or about two-thirds the usual quantity; a drought which in the first instance led to the scarcity of food, from which these provinces are only now emerging. To complete my mortification, I found that the colli-

* A range of hills to the eastward conceals the view for some degrees in altitude; so that, though I have repeatedly watched the spectrum of a morning as well, my map is in preference based on the view at sunset, when the sun can be followed down to the horizon.

mator of the spectroscope had bent, by its own weight, at the flanges where it unites with the drum; and this deterioration involved remedies for which the available means were but too limited. In this way the autumn of 1868 passed away, to my great disappointment, without bringing me any results save experience; and I eventually left Mussoorie, as usual, for the winter of 1868–69, to carry on my survey duties at Dehra.

7. *Narrative continued.*—On my return to this place about the end of April 1869, I found, as was to be expected, that, owing to the small amount of rain in the winter, the hazy state of the atmosphere still continued; so that it was not until last October (1869) that I was able fairly to commence work at sunset. Even then I had to discover by experiment that, to observe the full atmospheric effect on the spectrum, I must command a view of the sun down to the very horizon. To suit this new condition, I had to shift the spectroscope twice to adjoining positions, and to modify the map I had already prepared.

8. *Construction of spectroscope.*—The spectroscope is made up of a drum containing three flint-glass prisms, one of which may be made non-effective at pleasure. The collimator unfortunately consists of three pieces, of which the nearest portion is rigidly fixed to the drum. The second piece unites with the drum piece by means of three screws driven through flanges; the third piece, which unscrews for packing, bears the slit at its far end. The spectrum is viewed by a telescope provided with four eye-pieces, whose magnifying-powers I determined with a dynameter to be as follows:—

Eye-piece.	Power.
No. 1	9
No. 2	17
No. 3	25
No. 4	54

A graduated circle and vernier, read by a side-telescope, provide the means for measuring distances between the lines; and the foregoing are mounted equatorially on a tripod-stand.

9. *Details.*—In observing the spectrum sun high, I was soon struck by the difference in intensity of the lines as seen at Mussoorie and as given in Kirchhoff's well-known map. Excepting the decided lines A, B, C, and D, all the others appeared comparatively faint, and even wanting in definition. It is also worthy of remark, that while Kirchhoff used a power of forty to view the spectrum with, I am unable to employ any higher power than eye-piece No. 2 (power 17). My observations were thus made with eye-piece No. 2, using all three prisms; and this combination, the most powerful at my command, produced an image only some three-tenths of what Kirchhoff, I presume, actually saw.

10. *Details.*—The comparative smallness of image presented to view has necessarily added sensibly to the difficulties of the undertaking; for,

understanding the Committee to suggest that I should adopt Kirchhoff's map *and scale* as a basis, it became incumbent on me to magnify the image actually viewed some three times before sketching it on my map. As an aid towards this end, I removed the strong metal *cross* wires in the telescope, and replaced them by two tolerably stout silk fibres, *parallel* to one another, and rather more apart than the image of B sun high. I could thus compare a given line with one of the fibres, or, where more convenient, with the space between them; and, through the intervention of the fibres, compare any one line with any other. These comparisons of magnitude were thus all mental, there being no micrometer in the eye-piece to measure small spaces with, and the smallest quantity that I could measure on the circle being the distance between the two lines in D. In selecting a relative unit between Kirchhoff's and my map, I have adopted the breadth he has assigned to the line A. This line will therefore be found equally wide in his map and in mine at sunset. The necessity for enlarging the image leads to an unintentional deception, deserving notice. It will be seen that my line A, for instance, is *equally* and intensely black throughout; whereas the same line, shown at the same width in Kirchhoff's map (402 to 407), is made up of several lines of varying intensity. This difference is due to the lesser power of my instrument; and in all probability the line up here would decompose into its component lines under greater dispersion.

11. *Necessity for constructing my map from independent measures.*—The want of intensity generally in the spectrum sun high at Mussoorie, combined with the smaller power of the instrument, made it exceedingly difficult, and in most cases impossible, to identify individual lines in Kirchhoff's map with corresponding ones under view; so that, after making every endeavour at identification, I was obliged to content myself with adopting the positions (sun high) assigned by him to the strong lines A, B, C, and D, and to place all the other lines of sensible intensity by means of differential measures and interpolation. Practically speaking, this amounted to the construction of a new map, so far as my wants were concerned.

12. *Definitions.*—By a constant line is intended one that presents the same appearance at sunset or sun high; a variable grows darker at sunset, and, generally speaking, widens out; and an atmospheric or air-line is invisible only sun high. By a band may be understood those broad belts which suddenly appear like shadows at sunset; instances of bands occur on both sides of C and elsewhere.

13. *Lines mapped.*—*Every* variable or air-line (or band) sensibly visible has been measured and mapped; but of the constant lines only those sufficiently intense to be easily intersected were observed and placed. It appeared undesirable to crowd the map with a large number of faint lines, whose property of constancy made their presence in an atmospheric map redundant. On the other hand, the introduction of certain constant and

sufficiently intense lines proves valuable for purposes of identification. I may add in this place, that no lines whatever are here visible between B and C; and this fact will afford some means of estimating the relative intensity of spectrum viewed at Mussoorie and that mapped by Kirchhoff.

14. *Direct sunlight employed.*—On first commencing work, I endeavoured to follow the plan adopted by Kirchhoff and employ a heliostat for reflecting the sun's rays; but, unlike the Professor, I was unable to command the clockwork for driving the heliostat. The variability of light under these circumstances proved intolerable; add to this the necessity for observing the sun as late in the evening as possible, made the introduction of any absorbing medium undesirable; and, lastly, the object of maintaining a constancy of circumstances between sun high and sunset, led me to prefer pointing the collimator direct to the sun. I therefore screened the drum and its prisms with an ample sunshade, and received the light from the sun directly on to the slit of the spectroscope.

15. *Identification of constant lines.*—It will be seen that in the space A to C there appears but little for recognition. No doubt the following groups are, generally speaking, identical, viz.:—

My map, sun high.		Kirchhoff's map.
Group 469–492	is the same as	470–492.
„ 499–508	„ „	498–509.
„ 570–586	„ „	570–587.

But the component lines, group by group, are widely different, and several sensibly intense lines in the Professor's map between 541 and 564 are absent here.

16. *Constant lines, continued.*—In the space C to D the identification is more frequent and definite. My 711 and 719 are clearly represented in Kirchhoff's map, and between the latter line and 795 several other cases of identity occur. Further on, towards D, the resemblance is not clear; until on arrival at the variable lines between my 955 and D recognition becomes impossible. Remembering that my map has been prepared from perfectly independent measures, I am naturally glad of establishing identification, where possible, with the Professor's map, for the evidence such identity offers of the accuracy of my work. Until my map had been *finished*, and the scale of millimetres drawn above it, the means of making a comparison were all wanting.

17. *Comparison of variable and air-lines.*—In discussing the variable and air-lines, I much regret my inability to adopt the suggestions of the Committee, and institute a comparison with Sir David Brewster's and Dr. Gladstone's map given in the Philosophical Transactions for 1860. The volume in question is, unfortunately, one of the few of its kind not at present included in the library of the Great Trigonometrical Survey; nor am I aware that any other library in these provinces possesses a copy. The only map of the kind to which I have access is that by Janssen, given in

Roscoe's Spectrum Analysis, fig. 57. The scale adopted in this diagram is, however, only about half that of Kirchhoff's, and the lines are so very numerous that identification is exceedingly difficult. It is evident, however, that my 812, a notably variable line, is identical with his 254.

18. *The same, continued.*—Comparing with the lines numerically alluded to by Kirchhoff in his appendix as atmospheric lines, the following coincidences (nearly) appear :—

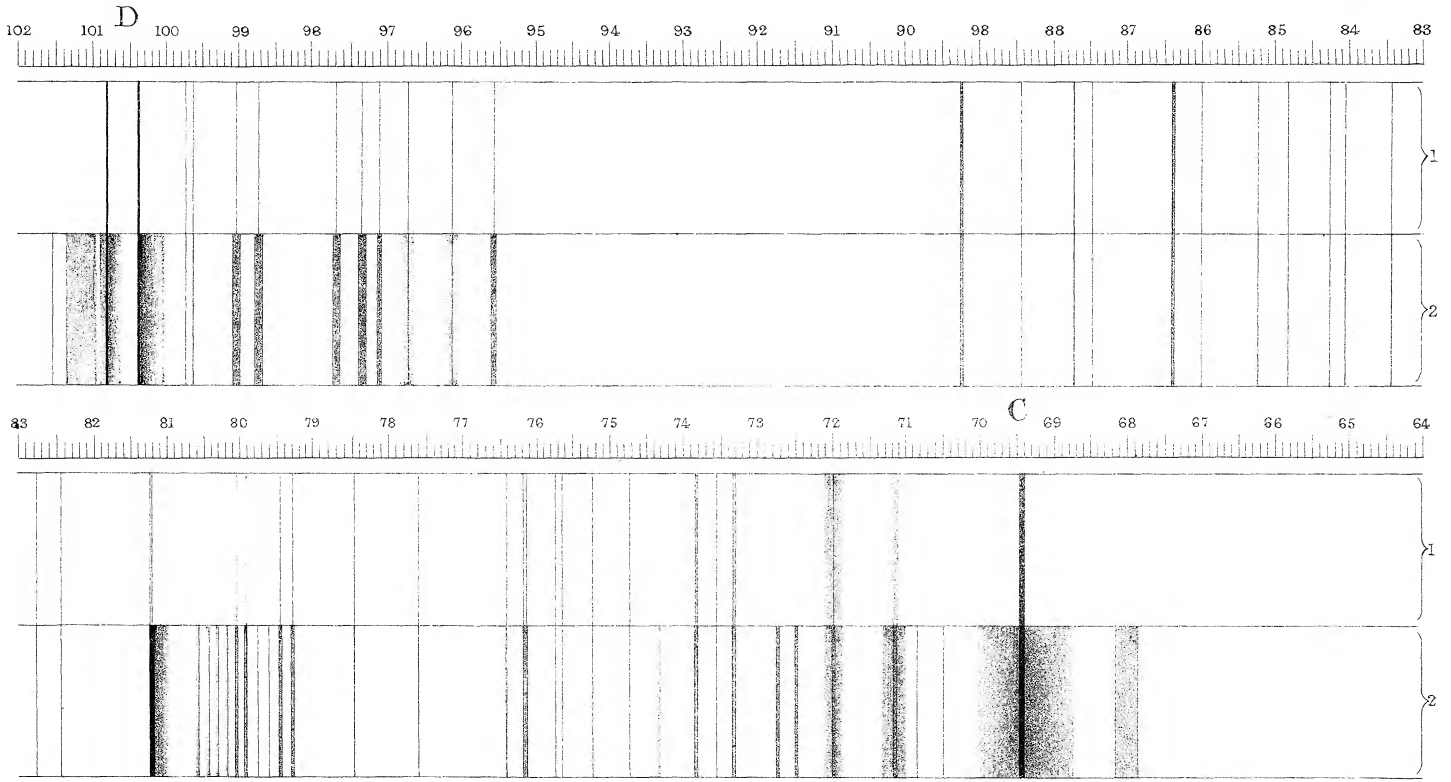
My map at sunset.	Kirchhoff's list of atmospheric lines.
711	711·4
955	954·2
961	961·
967	965·7, 968·7
971	970·5
973	972·1
977	977·4
987	988·9
990	989·6

In assuming the foregoing identities, I have been guided necessarily merely by numerical coincidences. *All* the foregoing, in the proposed nomenclature, are variable lines, not air-lines.

19. *Discussion of air-lines and bands.*—Again, comparing my map sun high with that at sunset, and beginning from the red end, the first group met with are the air-bands 262 to 302. These bands, so far as I am aware, have not been placed before, if seen. I have seen and taken measures to them repeatedly; but without the interposition of a blue glass they were invisible. The slit, too, must be sensibly widened. The whole group is nearly at the end of the luminous rays, where, at sun high, almost complete darkness prevails; and after careful watching of this group, I cannot help entertaining the belief that the *range* of the luminous rays *increases* towards the red end of the spectrum *as the sun approaches the horizon*. With the sun high, hardly any light reaches so far as 262 of the scale. When, however, the sun is setting, this part of the spectrum lights up sensibly. I am even inclined to assert that other bands exist still further removed from A than the group under notice; they, however, appeared too faint for intersection. May it not be anticipated that, at considerable terrestrial altitudes, an extension of the spectrum will occur both at the violet and red ends?

20. *The same, continued.*—Between 508 and 570 a very marked succession of air-lines and bands occur. Indeed, so far as I have been able to glance at the spectrum *in general*, the most refrangible rays appear the most liable to absorption. The air-bands about C and D are worthy of notice, as also are the air-lines 724 and 726.

21. *Discussion of variable lines.*—Both A and B appear as lines of this


D
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C
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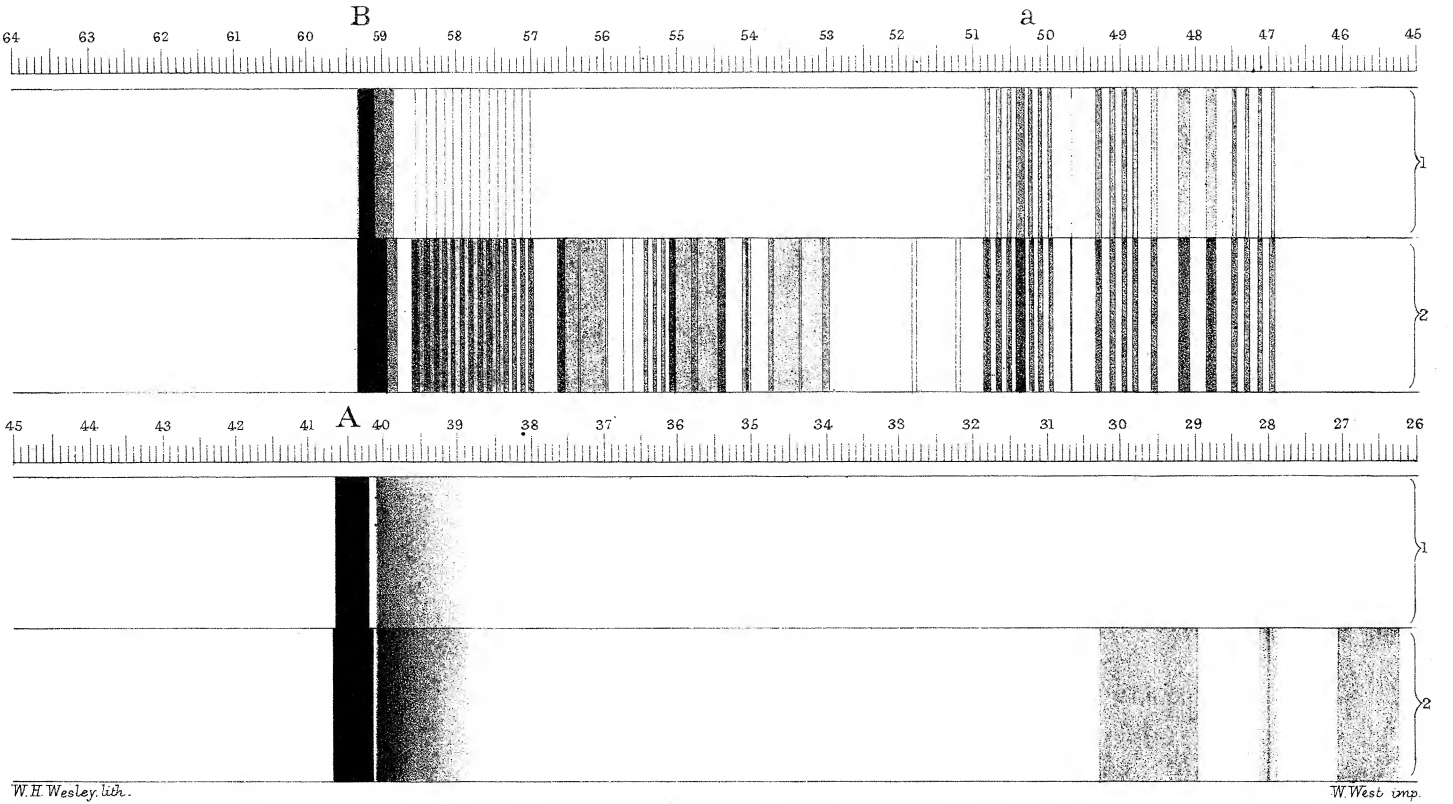


1. PART OF THE SOLAR SPECTRUM AS SEEN BETWEEN 10 A.M. & 2 P.M.
2. PART OF THE SOLAR SPECTRUM AS SEEN AT SUNSET.

class. In the absence of a micrometer for measuring small spaces, I have assumed that in widening out at sunset A does so equally on both sides; on the contrary, B, I believe, maintains its left (or violet) edge constant, and changes towards its right (or red) edge. The line 812 is the most notably variable I have observed. Unlike other lines, it commences to change quite two to three hours before sunset. The darkening is gradual until near sunset, when it suddenly becomes black, and the band to the right as suddenly appears. The variable lines are, however, so numerous, that further notice of them might prove tedious reading. I therefore content myself by calling attention to the fact that, so far as I have the means of judging, the variable lines at sunset and sun high superpose one another, —more accurately speaking, on the former occasion, when they are generally wider, they include the position occupied sun high. I need hardly dwell on the circumstance that the loss of light which no doubt occurs near sunset *cannot* be the cause of the widening out in these lines; for constant lines, identified with Kirchhoff's, stand mapped in the vicinity of variable lines of greater and lesser refrangibility.

22. *Concluding remarks.*—At the time of writing the air is so laden with dust that you may gaze on the setting sun with impunity; and spectroscopic observation, even at several degrees of altitude, is impossible. But when the ensuing rainy season is approaching its termination, and the exquisitely clear state of atmosphere once more returns, I hope to make good progress with the map; and also to try and ascertain*, by comparison of the map already made with the actual objects, if the variable and atmospheric lines and bands change their appearance from time to time. A variation of the latter kind might open out a vast field of inquiry.

23. *Proposed alteration of spectroscope.*—Though quite willing meanwhile to continue the work with the spectroscope as it now stands, I should consider it a great boon if you would allow me to send it to England for certain improvements. These I briefly indicate as follows:—1. One or even two additional prisms might be introduced into the drum, so as to increase the dispersion. 2. The collimator should be made up into *one* piece with the drum, and this may be done simply by uniting the present three pieces firmly together. 3. A micrometer introduced at the eye-end of the telescope would be invaluable. The stand answers every purpose, so that it might be useless sending it home, unless any delay is likely to occur in improvising a stand to adjust and test the instrument. Should I receive a favourable reply by the return mail, the spectroscope ought to reach Messrs. Troughton and Simms by the end of July; and if they could undertake to do the needful alterations by the end of August, it would, if despatched immediately overland, reach me about the first week in October, just in time for the fine weather. Unless, however, these dates are not exceeded, I should lose the observing season, and this would be lamentable.

24. *The same.*—Even should the foregoing meet with approval, I am

* Report of the Committee, last paragraph of § 4.

aware that without suitable supervision the alterations could not be carried out satisfactorily; and in saying this, I make no doubt that Messrs. Troughton and Simms would perform their part in their usual effective manner. I already owe Mr. Huggins a considerable debt of gratitude for past superintendence; and his kindness on that occasion induces me to venture the hope that he would undertake to direct such alterations as may be approved of with despatch.

25. *Zodiacal light.*—Every attention has been given to this subject, but the only result obtained is, that no traces whatever of the zodiacal light are visible here. I was on the watch in October and the early part of November 1868. In April and May of 1869 my absence on duty at Dehra prevented my devoting more than an occasional evening to the subject. Last autumn, however, I gave it every attention, but all without seeing the light. The following extract from my note-book, made the first morning of my watching last winter, is a representative of all subsequent entries:—

13th October, 1869. Mussoorie Observatory.—A beautifully clear morning. Not a speck of cloud or mist to be seen. The horizon, S.S.E. by S. to S.S.W., appears sharp and distinct, though some 90miles distant. To the north, the snowy range, though some 60 miles away, appears hardly a day's journey from this. The light is gradually increasing; the red rays now tinge the sky; the sky itself brightens; the highest peaks of the snowy range are tipped with light; the sun bursts over the hills as if in a moment. All this has happened without any wings or rays preceding the sun. In other words, no traces of the zodiacal light have appeared.

26. *The same, continued.*—I watched for the light on the mornings of the 14th, 18th, 21st, 23rd, and 29th October, and on the 1st, 9th, and 15th November, 1869. On all these occasions the air and sky were beautifully clear. Other dates of watching, under *un*favourable circumstances, are excluded from this list. Though no zodiacal light appeared to me at Mussoorie, it is worthy of remark that Colonel Walker, while travelling by post across the plains of Central India, saw a brilliant show of the light (as far as I can reckon) between the 12th and 15th of November, 1869. Recently I watched for the light on the evenings of the 11th, 12th, 13th, and 14th April, 1870, with the same results as before.

27. *The same, conclusion.*—How far these facts supply a connecting-link between the earth's atmosphere as a medium and the zodiacal light I leave for the consideration of more competent authorities. The information may have some special interest for Mr. Balfour Stewart, who, I learn from the monthly notices of the Royal Astronomical Society, has given the subject some attention.

28. *Actinometrical observations.*—Discussion of these observations is deferred until, with the assistance of Mr. W. H. Cole, M.A., I am able to reduce and forward the results already obtained. The two actinometers (Hodgkinson's) work capitally, and are in good order. Amongst other observations, they have been compared with one another. Unfortunately

a press of other work precluded them from comparison with the instrument (standard) at Kew Observatory. After inspection of the observations, you may be good enough to consider the desirability of sending me a third actinometer of the same kind, due comparison being first made at Kew, whereby the relation between the instrument at the Observatory (Kew) and those sent out to me by the Royal Society may be established.

XV. "On the Radiation of Heat from the Moon.—No. II." By the Earl of Rosse, F.R.S. Received June 14, 1870.

In a former communication to the Royal Society I gave a short account of some experiments on the radiation of heat from the moon, made with the three-foot reflector at Parsonstown, during the season of 1868–1869. I then showed:

1st. That the moon's heat can be detected with certainty at any time between the first and last quarter, and that, as far as could be ascertained from so imperfect a series of observations, the increase and decrease of her heat, with her phases, seems to be proportional to the increase and decrease of her light, as deduced by calculation*.

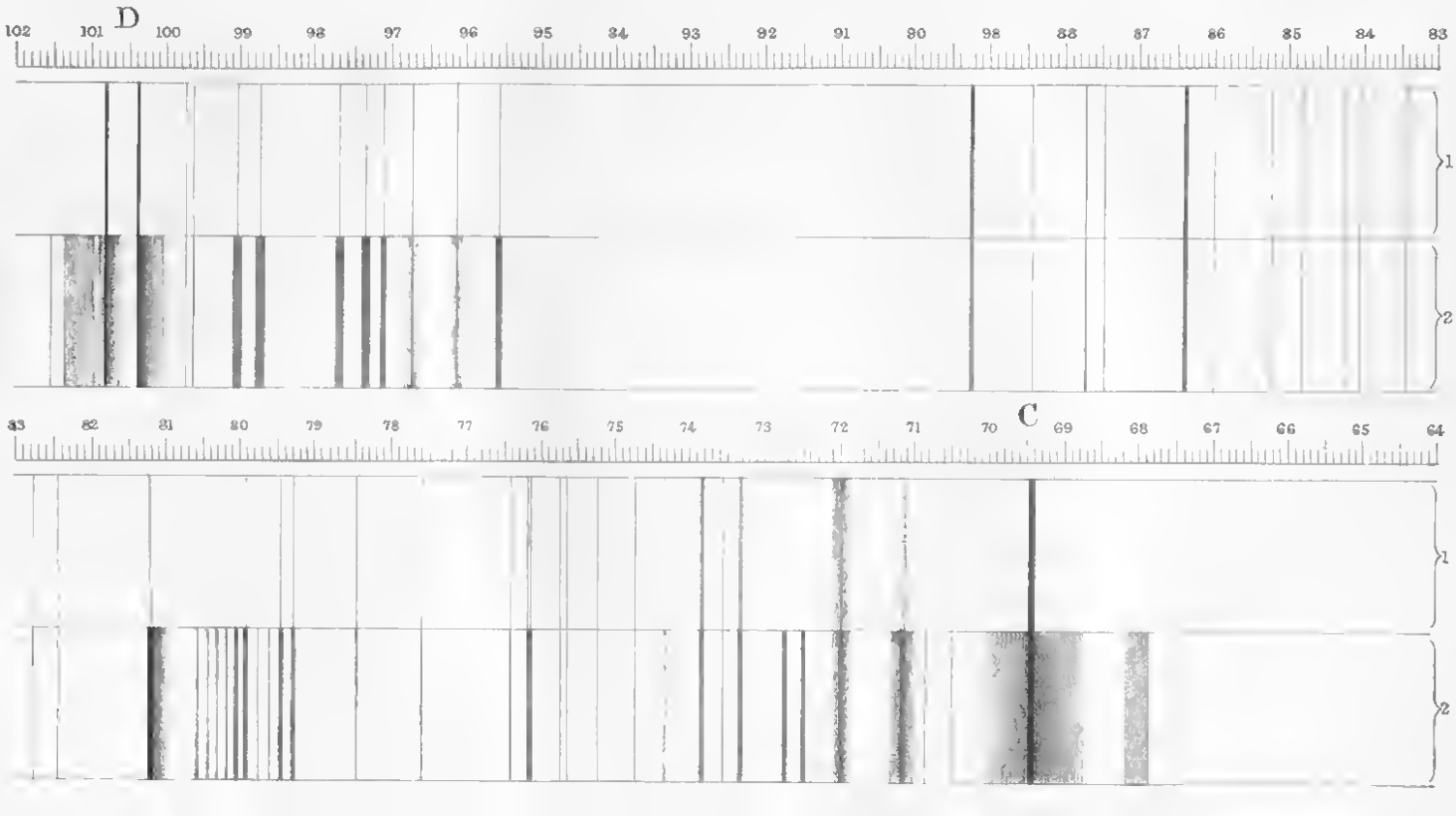
2ndly. That a much smaller percentage of lunar than of solar rays is transmitted by a plate of glass, and we therefore infer that a large portion of the rays of high refrangibility, which reach the moon from the sun, do not at once leave the moon's surface, but are first absorbed, raise the temperature of the surface, and afterwards leave it as heat-rays of low refrangibility.

3rdly. That, neglecting the effect of want of transparency in our atmosphere, and assuming, in the absence of any definite information on the subject, that the radiating-power of the moon's surface is equal to that of a blackened tin vessel filled with water, the lunar surface passes through a range of 500° F. of temperature; consequently the actual range is probably considerably more.

4thly. The proportion between the intensity of sunlight and moonlight, and between the heat which comes from the sun and from the moon, as deduced from those observations, agreed as nearly as could be expected with the values found by independent methods, and for this reason might be considered the more reliable.

During the past season these observations have been continued, but much time has been spent in trying various modifications of the apparatus, and a satisfactory comparison of observations made on different nights, under different circumstances, has been impossible; however, by more numerous and more complete experiments, made alternately with and without an inter-

* See the Proceedings of the Royal Society, No. 112, 1869, page 439.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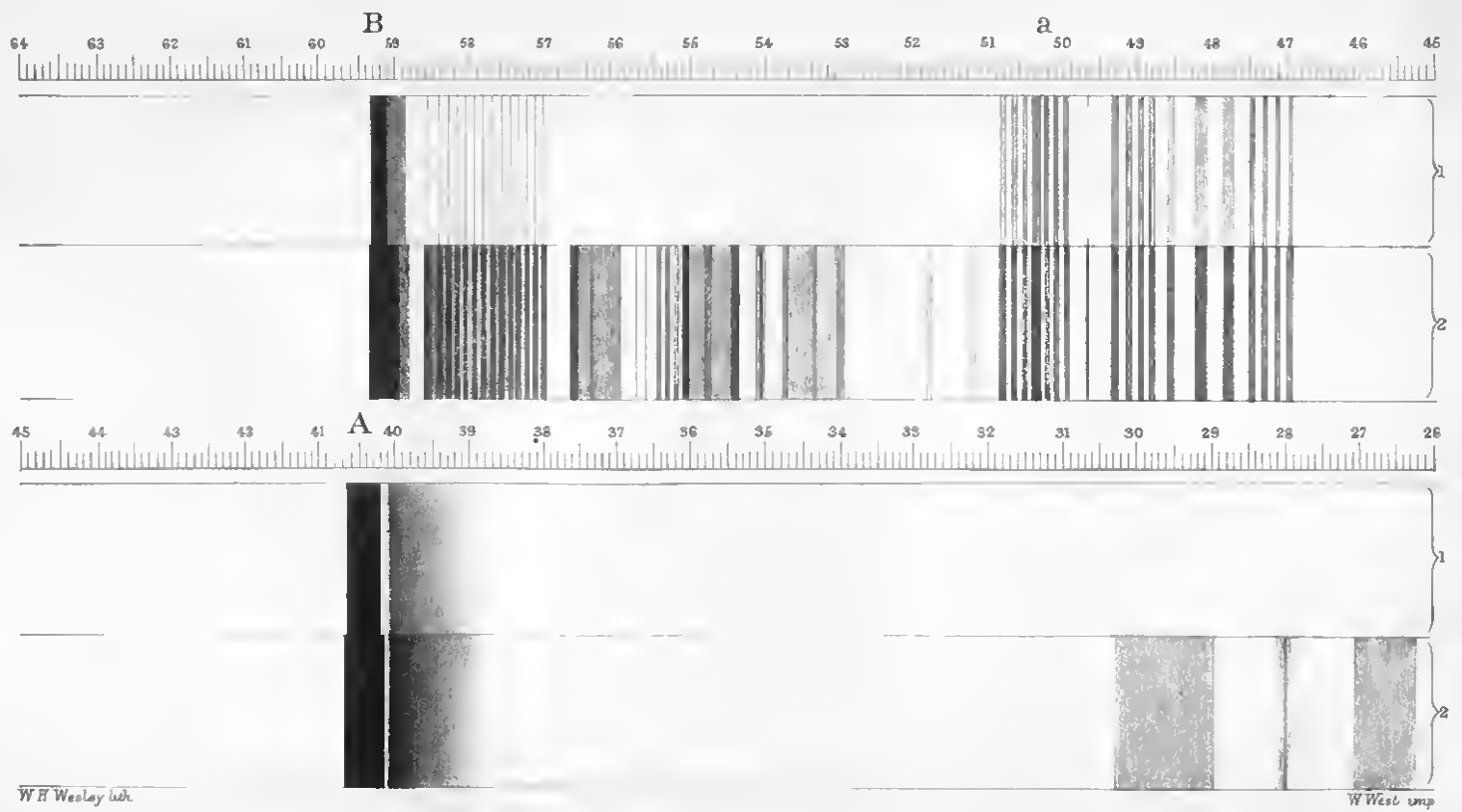

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